Land Suitability Evaluation for Organic Agriculture of Wheat Using GIS and Multi-Criteria Analysis

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Abstract:

Despite the growing interest in organic farming, its practice remains limited because of its lower productivity relative to conventional farming. Land suitability evaluation for organic crops can potentially improve productivity, and thus the economic viability of organic farming. The best analytical procedures for such evaluations have not yet been fully explored. This article addresses the evaluation of land suitability of present agricultural lands for organic agriculture of rain-fed winter wheat using Duplin County, North Carolina, a location economically dependent on agriculture, as a case study. A novel land suitability evaluation procedure is developed combined with seventeen suitability criteria from five principal categories including climatic parameters, soil characteristics and qualities, soil chemistry, soil organic matter and fertility, and flood and erosion hazards by using geographic information systems (GIS), multicriteria analysis, and the square root method. Our analysis demonstrates that although 18.6 percent of agricultural lands in Duplin County are highly suitable for organic winter wheat production, a large proportion (76.8 percent) of agricultural lands are also moderately suitable. The method of suitability analysis used in this research, which allows specific consideration of soil organic matter and fertility as particularly critical factors for organic farming, can be easily exported to other locations, for similar applications.

Keywords: GIS | land suitability evaluation | multicriteria analysis | organic agriculture | wheat

Article:

In recent decades, organic farming has been receiving much attention in the United States and many other countries, because of its environmental and health benefits relative to conventional agricultural practices (Läpple and Cullinan 2012). Relying on ecological processes, organic farming practices not only protect the health of soils and ecosystems (IFOAM 2008), they also enhance biodiversity in agricultural landscapes for vascular plants and birds (Freemark and

Kirk 2001; Hyvönen *et al.* 2003). Rare species often found in farms are also protected in organic farms (Gabriel and Tscharntke 2007). Additionally, organic farming reduces the total use of water and energy, which consequently reduces the greenhouse gas emissions from food production (Wood *et al.* 2006). Organic products not only have higher nutritional and health benefits (AFSSA 2003; Schoonbeek *et al.* 2013; Jouzi *et al.* 2017), but they also have lower amounts of chemical residues than conventional foods (Johansson *et al.* 2014). Organic foods also are less contaminated with pesticides and residues of toxicity like nitrates compared to conventional foods (Lairon and Huber 2014; Reganold and Wachter 2016). Exposure to pesticides and chemical residues from the conventional foods could increase the probability of some type of cancers, such as breast cancer in women (George and Shukla 2011; Wang, Guo, and McLafferty 2012; Mu *et al.*2015).

Despite the substantial benefits of organic farming practices, their lower productivity compared to conventional agriculture practices remains challenging (Ponti, Rijk, and Ittersum 2012; Seufert, Ramankutty, and Foley 2012; Jouzi *et al.* 2017). The key issue is whether organic agriculture can be economically competitive with conventional agriculture given that it requires more land to produce the same volume (Seufert, Ramankutty, and Foley 2012). A few recent studies (*e.g.,* Ponti, Rijk, and Ittersum 2012; Seufert, Ramankutty, and Foley 2012) have demonstrated that the volume of organic agricultural production depends on both the agriculture system and the characteristics of agricultural land. To maximize organic production, it is essential to find land with suitable characteristics for organic agriculture, and this requires robust analytical methodologies for land suitability evaluation (Mishra, Deep, and Choudhary 2015).

Land suitability evaluation is the examination of land potential for a specified utilization (Sys, Ranst, and Debaveye 1991; Food and Agriculture Organization [FAO] 2007). Climatic, spatial, soil, vegetation, and other characteristics of lands are examined in land suitability evaluation to identify appropriate lands for specified uses (Sys, Ranst, and Debaveye 1991; FAO 2007; Akıncı, Ozalp, and Turgut 2013). Definition of criteria affecting the suitability of lands is one of the most important parts of this evaluation (Akıncı, Ozalp, and Turgut 2013). A variety of criteria can be used to evaluate land suitability for agricultural uses considering various factors including farming methods, data availability, precision of evaluation, environmental characteristics of the study area, and type of crop. These suitability criteria can be classified into four general classes: climatic parameters, soil characteristics, topographic properties, and natural hazards. The significant criteria and requirements for various major crops have been investigated in several studies such as FAO (1983, 1985), Sys *et al.*(1993), Naidu *et al.* (2006), and Moore (2001).

Much literature on agricultural land suitability is based on conventional farming practices (*e.g.,* Table 1), yet relatively few papers emphasizing land suitability evaluation for organic production in the United States and particularly North Carolina are available. Methods developed for the evaluation of land suitability for conventional agriculture are generally divided into limitation and parametric approaches (Table 1). Simple limitation, regarding number and intensity of limitations, Storie, and square root (Khiddir 1986) methods are the most widely used (Sys, Ranst, and Debaveye 1991; Rabia and Terribile 2013). Comparative evaluations of the different land suitability methods have been presented by Hopkins (1977) and Anderson (1987). Although results of different land suitability methods are generally similar, the parametric methods frequently underestimate the potential of investigated lands (Rabia and Terribile 2013). Jafarzadeh and Abbasi (2006), Jafarzadeh *et al.* (2008), and Sarvari and Mahmoodi (2001) demonstrated more realistic results for agricultural land suitability using the square root method evaluation. The majority of both limitation and parametric methods use the FAO (1976) framework for land suitability classification. In this framework, lands are classified into five classes ranging from highly suitable to permanently not suitable considering the existing limitations for a specific use (FAO 1976).

Table 1. Selective studies of land suitability evaluation.

Author	Year	Methods	Crop	Criteria
Jafarzadeh and Abbasi	2006	Simple limitation method, limitation method regarding number and intensity, square root and Storie methods	Onion, potato, maize, and alfalfa	Soil depth, clay, texture, pH, $CaCO_3$, EC, CEC
Perveen *et al.*	2007	GIS and AHP	Rice	Soil texture, soil moisture, soil consistency, soil pH, soil drainage, soil organic matter, slope, LULC
Jafarzadeh *et al.*	2008	Simple limitation method, limitation method regarding number and intensity, square root and Storie methods	Wheat, barley, alfalfa, maize, and safflower	Climate characteristic, soil horizon, soil depth, texture, pH, $CaCO_3$, EC, CEC
Keshavarzi *et al.*	2010	Fuzzy AHP	Irrigated wheat	Soil classification, slope, ESP, OC, EC, gypsum, soil texture, climate, soil depth
Bagherzadeh and Mansouri	2011	GIS with Storie method, square root method, and Kalogirou method	Wheat, barley, grain, maize, and sorghum	Climatic characteristics
Rabia and Terribile	2013	GIS with AHP, Storie method, and square root method	Wheat	Organic matter, $CaCO_3$, pH, slope, soil texture, drainage, soil depth, EC, and altitude
Akıncı, Ozalp, and Turgut	2013	GIS and AHP	General	Soil group, land use capability class, land use capability subclass, soil depth, erosion degree, OSP, slope, elevation, aspect
Hailu, Kibret, & Gebrekidan	2015	Maximum limitation method	Barley and wheat	Climate characteristic, oxygen availability, nutrient availability, nutrient retention capacity, rooting condition, soil workability, flood hazard, erosion hazard
Mishra, Deep, and Choudhary	2015	GIS and AHP	Organic crops	Drainage, road, soil, geology, LULC, slope
Pramanik	2016	GIS and AHP	General	Slope, elevation, aspect, LULC, soil moisture, drainage, rransport network, soil characteristics, geology

In addition to the aforementioned methods, new spatial technologies such as geographic information systems (GIS) and remote sensing as well as multicriteria decision-making methods such as an analytical hierarchy process (AHP) and fuzzy AHP can be used to enhance land suitability evaluation (Table 1). GIS technology enables users to integrate multiple geospatial and attribute data sts with high precision and flexibility and hence improves land suitability evaluation (Bagherzadeh and Mansouri 2011; Mendas and Delali 2012; Khahro *et al.* 2014; Hamerlinck and Lieske 2015). Furthermore, GIS facilitates spatiotemporal analysis of various crop production practices (Laingen 2015; Flynn 2016). Almost all land suitability evaluation studies today use the integration of GIS and other suitability evaluation methods (Perveen *et al.*

2007; Mustafa *et al.* 2011; Akıncı, Ozalp, and Turgut 2013; Rabia and Terribile 2013; Nowlin and Bunch 2016; Pramanik 2016). A number of studies also applied AHP and fuzzy AHP to evaluate agricultural land suitability (Keshavarzi *et al.* 2010; Xu and Zhang 2013; Alkimim, Sparovek, and Clarke 2015; Mighty 2015; Mishra, Deep, and Choudhary 2015; Pramanik 2016). These multicriteria decision-making methods are used to determine weights of the considered criteria through a pairwise comparison technique (Saaty 1977). These weights are directly entered into the suitability evaluation method to consider different importance levels for the criteria.

This article addresses land suitability evaluation for organic agriculture of rain-fed winter wheat using Duplin County, North Carolina as a case study. Organic production of wheat has considerable potential to improve human health and environment because wheat is one of the most important components of human food for the food industry. A novel suitability evaluation for organic farming is developed for our study using a combination of GIS, multicriteria analysis, and the square root method. This approach involves the categorization of suitability criteria into a number of major groups on the basis of the results from previous studies, expert comments, and their importance for organic agriculture. The aggregation of land suitability values of the major groups is accomplished using a method with multiplying nature known as the square root method. This categorization considers different weights for each criterion indirectly and due to the multiplicative nature of the evaluation method, low values for each major group indicate unsuitability for organic farming. Because of the conspicuous role of organic matter and natural soil fertility in organic agriculture, these criteria are considered as a separate major group. These criteria are not as critical in conventional agriculture because they can be modified or compensated for by using chemical fertilizers.

The article is organized into three sections. First, the study area and methods of evaluation, including evaluation criteria and collected data sets, are described. Results of the evaluation based on the FAO (1976) framework for land suitability classification are then presented and discussed by considering the relative influence of different criteria on the outcome. Finally, advantages and challenges of the applied suitability evaluation together with recommendations for future research are presented in conclusion.

Study area, criteria, and methods

Study area

North Carolina is one of the top ten agricultural and winter wheat producing states in the United States and Duplin County (Figure 1) is one of the leading locations for winter wheat production in North Carolina (U.S. Department of Agriculture [USDA] 2012). Given its coastal plain physiography, considerable area of this county (35.6 percent) is covered by agricultural land uses (Natural Resources Conservation Service [NRCS] 2016). The elevation of this county ranges from 0.6 m to 55.7 m and the annual average temperature and rainfall are approximately 17.2°C and 1,200 mm, respectively. The average lowest and highest temperatures vary between 1.0°C and 31.9°C, which occur in January and July.

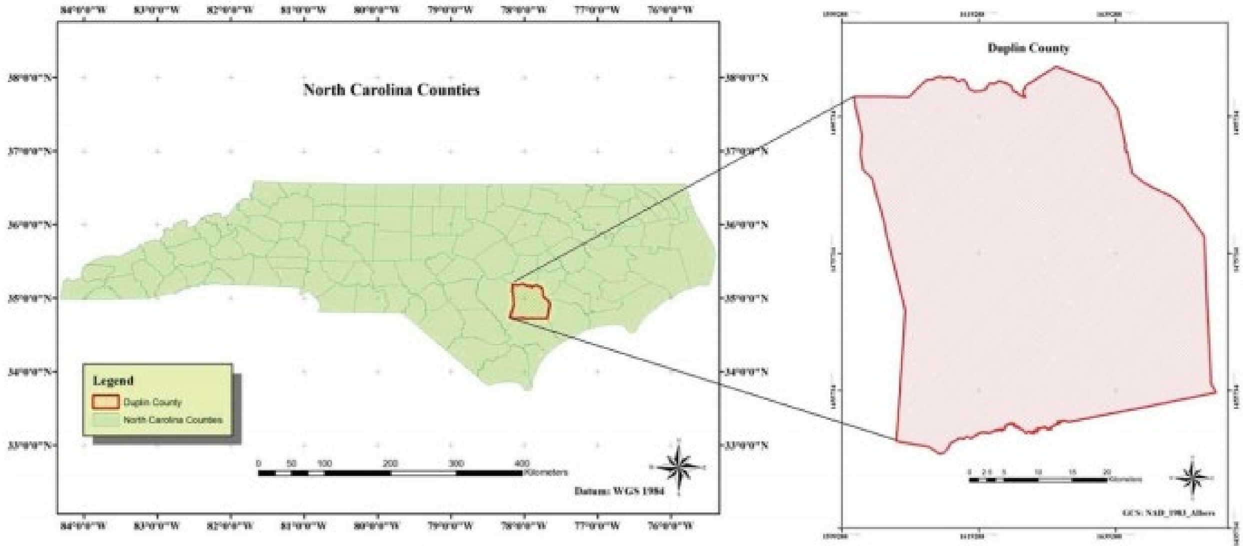

Figure 1. Study area: Duplin County, North Carolina.

Table 2. The considered criteria and requirements for rain-fed winter wheat agriculture.

		Suitability classes and rating ranges				
		S1	**S2**	**S3**	**N1**	**N2**
Major group	**Criterion**	**100–95**	**95–85**	**85–65**	**65–40**	**< 40**
Climatic parameters	Mean temperature (°C)	15–25	10–15 25–30	8–10 35–40	—	< 8 > 40
	Total rainfall (mm)	350–1,250	250–350 1,250–1,500	200–250 1,500–1,750	—	< 200 > 1,750
Soil characteristics and qualities	Soil texture	Si, SiL, CL, SiCL, L	SC, SCl, C, SiC	SL, LS	SCm+60	S, CS
	Coarse fragments (%)	< 5	5–15	15–40	40–55	> 55
	Available water capacity (in./in.)	< 0.04	0.04–0.08	0.08–0.11	0.11–0.14	> 0.14
	Depth (cm)	> 90	50–90	30–50	20–30	< 20
	Drainage	Well-drained	Moderately well-drained	Poorly-drained	Very poorly-drained	—
Soil chemistry	pH	6.5–7.5	5.6–6.5 7.5–8.2	5.2–5.6 8.2–8.5	4.5–5.2	< 4.5 > 8.5
	Salinity	< 4	4–8	8–12	12–16	> 16
	Sodicity (ESP)	< 15	15–25	25–35	35–45	> 45
Organic matter and fertility	Organic matter (%)	> 1.5	0.8–1.5	0.4–0.8	< 0.4	—
	Carbonate calcium ($CaCO_3$) (%)	< 20	20–30	30–50	50–70	> 70
	Cation-exchange capacity (CEC)	>16	8–16	< 8	—	—
Flood and erosion hazards	Flood frequency	None, very rare	Rare	Occasional	Frequent	Very frequent
	Flood duration	Extremely brief	Very brief	Brief	Long	Very long
	Erosion (E_w)	< 0.2	0.2–0.3	0.3–0.4	0.4–0.5	> 0.5
	Slope (%)	0–6	6–10	10–20	20–30	> 30

Criteria and data description

Based on the literature and experts' opinions, seventeen significant criteria for organic agriculture of rain-fed winter wheat are considered in evaluating agricultural land suitability (FAO 1983; Sys *et al.* 1993; Delli, Martucci, and Sarfatti 1996; Kalogiroua 2002; Naidu *et al.* 2006; Bhagat *et al.* 2009; Hailu, Kibret, and Gebrekidan 2015). These criteria and their optimal values for rain-fed winter wheat production are presented in Table 2. The criteria are categorized into five major groups: climate parameters, soil characteristics and qualities, soil chemistry, soil organic matter and fertility, and flood and erosion hazards. According to the suitability degree for cultivation of winter wheat, values of each criterion are classified into five suitability classes ranging from highly suitable to permanently not suitable (Table 2). This classification is based on the FAO (1976) framework, which is the most commonly used framework for classification of agricultural land suitability (Table 3).

Table 3. Food and Agriculture Organization classification framework.

Suitability class	Class name	Rating range (1–100)	Class description
S1	Highly suitable	95-100	Land having no significant limitations or only minor limitations
S2	Moderately suitable	85–95	Land having limitations which in aggregate are moderately severe
S3	Marginally suitable	65–85	Land having limitations which in aggregate are severe
N1	Currently not suitable	40–65	Land having severe limitations which may be surmountable in time
N2	Permanently not suitable	< 40	Land having severe limitations

The spatial and attribute data describing the land suitability criteria for Duplin County are collected and prepared in ESRI ArcGIS 10.3 software. Soil data are derived from the Soil Survey Geographic Database 2016 (SSURGO) prepared by the USDA (NRCS 2016). Figure 2 and Table 4 show the major land/soil units and their characteristics in Duplin County. In addition, a 2011 land cover map of the study area at a spatial resolution of 30 m (Figure 3) was collected from the National Land Cover Database 2011 (Homer *et al.* 2015). This map is used as a constraint for restricting the suitability evaluation to agricultural lands. In the following, the criteria and soil data considered in this study are briefly explained.

Climatic parameters

Climatic parameters including temperature and total rainfall have significant effects on the production of rain-fed winter wheat. The growing period of winter wheat ranges from 180 to 250 days (Sys *et al.* 1993) and the recommended times for seeding and harvesting this crop in the State of North Carolina range from 20 November to 15 October and 9 June to 30 June, respectively (USDA 1997). The period of November to June is considered the growing period of winter wheat in the study area and climatic parameters are explored in this period. Table 5 presents the optimal values of climatic parameters together with their corresponding values in Duplin County for cultivation of winter wheat.

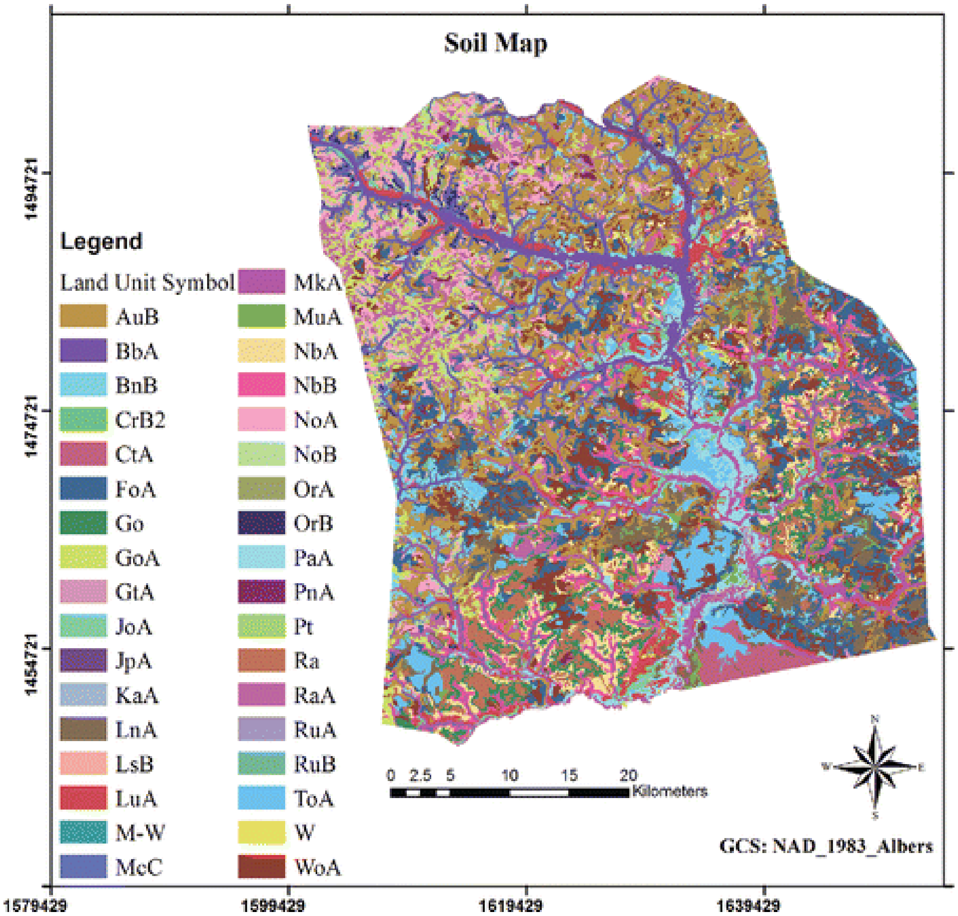

Figure 2. Major land units in Duplin County.

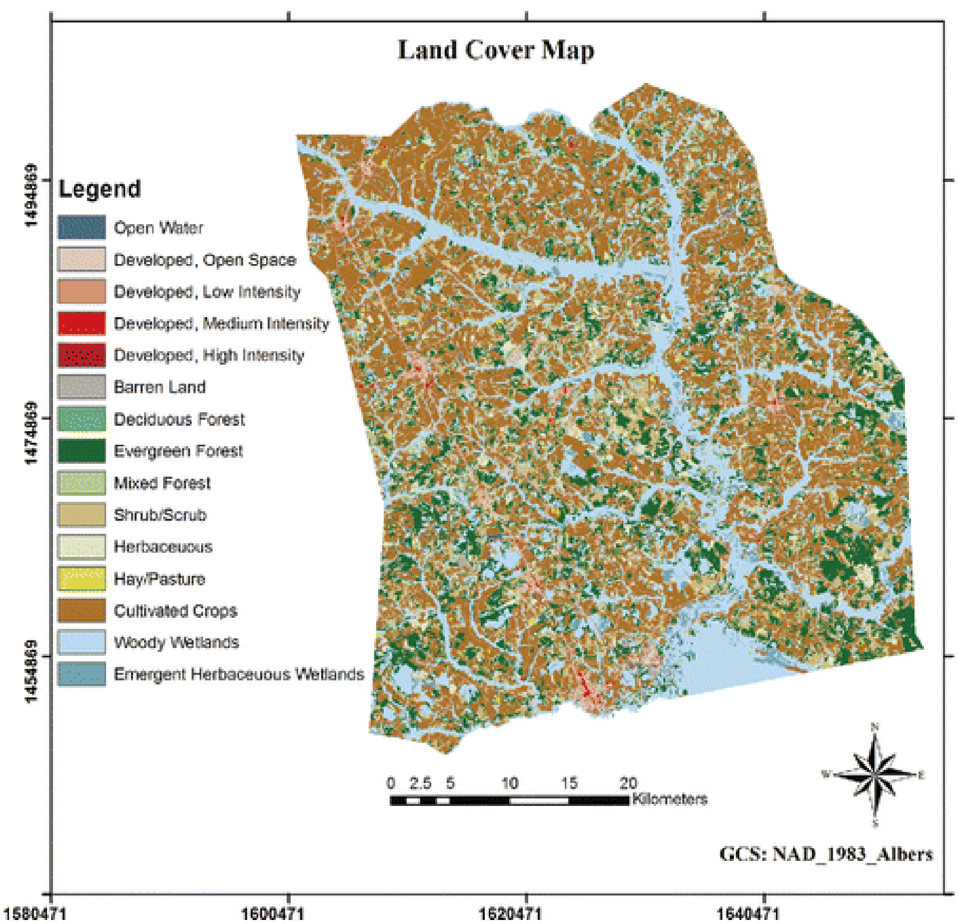

Figure 3. Land cover map of Duplin County.

Table 4. Major characteristics of land units in Duplin County.

Land unit symbol	Major characteristics of land unit	Area (ha)	Area (%)
AuB	Autryville loamy fine sand, 0 to 6 percent slopes	35,276	16.8
BbA	Bibb sandy loam, 0 to 1 percent slopes, frequently flooded	10,178	4.9
BnB	Blanton sand, 1 to 6 percent slopes	4,154	2.0
CrB2	Craven loam, 1 to 4 percent slopes, eroded	188	< 0.1
CtA	Croatan muck, ponded, 0 to 2 percent slopes	2,354	1.1
FoA	Foreston loamy fine sand, 0 to 2 percent slopes	20,075	9.6
Go	Goldsboro loamy sand, 0 to 2 percent slopes, Atlantic Flatwoods	6,757	3.2
GoA	Goldsboro loamy sand, 0 to 2 percent slopes, Southern Coastal Plain	7,882	3.8
GtA	Grifton fine sandy loam, 0 to 2 percent slopes	260	0.1
JoA	Johns fine sandy loam, 0 to 2 percent slopes	2,949	1.4
JpA	Johnston and Pamlico soils, 0 to 1 percent slopes, frequently flooded	1,050	0.5
KaA	Kalmia loamy sand, 0 to 2 percent slopes	335	0.2
LnA	Leon sand, 0 to 2 percent slopes	10,177	4.9
LsB	Lucy loamy sand, 0 to 6 percent slopes	1,456	0.7
LuA	Lumbee sandy loam, 0 to 1 percent slopes, rarely flooded	7,944	3.8
M-W	Miscellaneous water	527	0.3
McC	Marvyn and Gritney soils, 6 to 15 percent slopes	9,786	4.7
MkA	Muckalee loam, 0 to 1 percent slopes, frequently flooded	10,586	5.0
MuA	Murville mucky fine sand, 0 to 2 percent slopes	1,150	0.5
NbA	Noboco loamy fine sand, 0 to 2 percent slopes	7,546	3.6
NbB	Noboco loamy fine sand, 2 to 6 percent slopes	6,898	3.3
NoA	Norfolk loamy sand, 0 to 2 percent slopes	7,504	3.6
NoB	Norfolk loamy sand, 2 to 6 percent slopes	3,280	1.6
OrA	Orangeburg loamy sand, 0 to 2 percent slopes	340	0.2
OrB	Orangeburg loamy sand, 2 to 6 percent slopes	1,474	0.7
PaA	Pactolus fine sand, 0 to 3 percent slopes	7,239	3.5
PnA	Pantego loam, 0 to 1 percent slopes	738	0.4
Pt	Pits, quarry	121	< 0.1
Ra	Rains fine sandy loam, 0 to 2 percent slopes, Atlantic Coast Flatwoods	6,815	3.2
RaA	Rains fine sandy loam, 0 to 2 percent slopes, Southern Coastal Plain	7,659	3.7
RuA	Rumford loamy fine sand, 0 to 2 percent slopes	407	0.2
RuB	Rumford loamy fine sand, 2 to 6 percent slopes	962	0.5
ToA	Torhunta mucky fine sandy loam, 0 to 1 percent slopes	9,338	4.5
W	Water	824	0.4
WoA	Woodington loamy fine sand, 0 to 1 percent slopes	15,542	7.4

Table 5. Optimal values of climatic parameters together with their corresponding values in Duplin County for cultivation of winter wheat.

	Optimal values (Sys *et al.* 1993)				Duplin County's Values (Weather Underground 2017)			
	Temperature (°C)				Temperature (°C)			
Growing period	*M*	Min	Max	Total rainfall (mm)	*M*	Min	Max	Total rainfall (mm)
November–May	15–25	4	35	350–1,250	12.3	1	31.9	550

Soil characteristics and qualities

This major group includes the criteria of soil texture, available water capacity (AWC), percentage of coarse fragments, drainage, and depth. Soil texture is defined according to the size of soil particles represented by percentages of sand, silt, and clay in the soil (NRCS 2016). This parameter is one of the most fundamental characteristics of soil that influences soil moisture, drainage, infiltration, and retention capacity for nutrients and water (FAO 1979). AWC refers to the quantity of water that soil is capable of storing for use by plants, and it is an important factor for choosing appropriate crops in the study area (NRCS 2016). Percentage of coarse fragments is the percentage of soil particles with a diameter of more than 2 mm, which are not included in chemical, mineralogical, and some physical analyses. Soils having a high percentage of coarse fragments are less suitable for farming (NRCS 2016). "Soil drainage refers to the flow of water through the soil, and the frequency and duration of periods when the solum is free of saturation under natural conditions" (FAO 1979, p. 49). In the soil survey data of Duplin County, drainage has been classified into four general classes: well-drained, moderately well-drained, poorly-drained and very poorly-drained (NRCS 2016). Soil depth indicates the depth that can be effectively used by plant roots, and it is an important criterion that also influences the hydrologic and erosional properties of soils (Akıncı, Ozalp, and Turgut 2013). A soil depth of 90 cm is often selected as the minimum effective depth for highly suitable production of many crops (FAO 1979).

Soil chemistry

The criteria of sodicity, salinity, and pH of soil are grouped into this category. Soil salinity is a measure of soluble salts in the soil at saturation (NRCS 2016). It affects the suitability of soils for crop production through decreasing water availability, increasing ionic stress, and changing the cellular ionic balance (FAO 2002). In this study, sodium adsorption ratio (SAR) is used for defining soil sodicity. SAR is a measure of the amount of sodium relative to calcium and magnesium in water extracted from saturated soil paste (NRCS 2016). Excess concentration of sodium in the cation exchange complex of a soil results in the sodic soil. Sodic soils have poor physical and chemical properties that adversely affect water infiltration, water availability, and the growth of most crop plants (FAO 1988). Soil pH shows the degree of acidity or alkalinity of a soil. Soil acidity is important for evaluating soil amendments for fertility and stabilization and determining the risk of corrosion (FAO 1979; NRCS 2016). In general, highly acidic soils (pH <5.5) tend to have toxic amounts of aluminium and manganese and soils with high alkalinity (pH >8.5) tend to disperse, destroying natural soil aggregates that help main aeration, water infiltration, and erosion resistance.

Organic matter and soil fertility

In this major group, three influential criteria including organic matter, cation-exchange capacity (CEC), and calcium carbonate ($CaCO_3$) are considered, and these have particular significance for organic agriculture. The values for these characteristics can be compensated for by fertilizers in conventional farming. Therefore, in conventional agriculture, they are not as important as in organic agriculture. Soil organic matter is any decomposed materials in soil that are originally produced by living organisms (plant or animal). Organic matter has several positive influences on soil including serving as a revolving nutrient fund, decreasing chemical fertilizer use, improving soil structure, reducing herbicide and pesticide use, maintaining tilth, minimizing erosion, and eventually increasing productivity (FAO 2005). CEC is the maximum quantity of cations that can be held by a soil. CEC is used as a measure of fertility and nutrient retention capacity. Soils having lower CEC might require more frequent applications of fertilizer (NRCS 2016). Calcium carbonate ($CaCO_3$) is the percentage of carbonate in the < 2 mm particle size fraction which is not very soluble. Although moderate amounts of $CaCO_3$are useful for soil structure and correcting acidic soils, excess amounts of it cause nitrite accumulation and ammonium-N volatilization in soil and thereby restrict the availability of plant nutrients (NRCS 2016).

Flood and erosion hazards

The criteria of flood frequency, flood duration, water erosion, and slope are categorized into this group. Flood hazards influence the use, management, and development costs of agricultural lands (FAO 1979). In this article, flood frequency and flood duration are considered for evaluating flood hazards in the study area. In the soil survey data of Duplin County, flood frequency is categorized into six classes: none (flooding is not probable), very rare (the chance of flooding is less than 1 percent in any year), rare (the chance of flooding is 1 percent to 5 percent in any year), occasional (the chance of flooding is 5 percent to 50 percent in any year), frequent (the chance of flooding is more than 50 percent in any year but is less than 50 percent in all months in any year), and very frequent (the chance of flooding is more than 50 percent in all months of any year). Flood duration is categorized into five classes: extremely brief (0.1 hour to 4 hours), very brief (4 hours to 2 days), brief (2 to 7 days), long (7 to 30 days), and very long (more than 30 days; NRCS 2016). Soil erosion adversely affects physical, chemical, and biological properties of soil. It reduces the soil depth, organic matter, plant nutrients, and consequently the suitability of soil for cultivation. Slope is a critical factor in soil erosion, thus having similar unfavorable effects, and in addition, it restricts agricultural production by decreasing the possibility of mechanized farming (Akıncı, Ozalp, and Turgut 2013).

Suitability evaluation method

To evaluate land suitability, first, a parametric approach is applied for rating land units of the study area with respect to each criterion. In this approach, land units are rated on a numerical scale (1–100) according to the suitability degree of each criterion for cultivation of rain-fed winter wheat (Table 3). The maximum rating value of 100 is assigned to a land unit with optimal suitability for the considered criterion (Sys, Ranst, and Debaveye 1991). When data of a criterion are quantitative, a linear interpolation method is used for assigning a rating value of 1 to 100 to that criterion. In this method, a rating value of y in the interval [c, d] is assigned to an observed criterion's value of x in the interval [a, b] by applying the following formula (Kalogiroua 2002):

$$y = \frac{d-c}{b-a} \times x + c - \frac{d-c}{b-c} \times a$$

or

$$y = \frac{c-d}{a-b} \times x + \frac{ad-bc}{a-b}$$

It is noted that when data of a criterion are nominal or already classified, such as flood frequency, the middle rating value of an FAO class is assigned to that criterion for allowing numerical computing (Kalogiroua 2002).

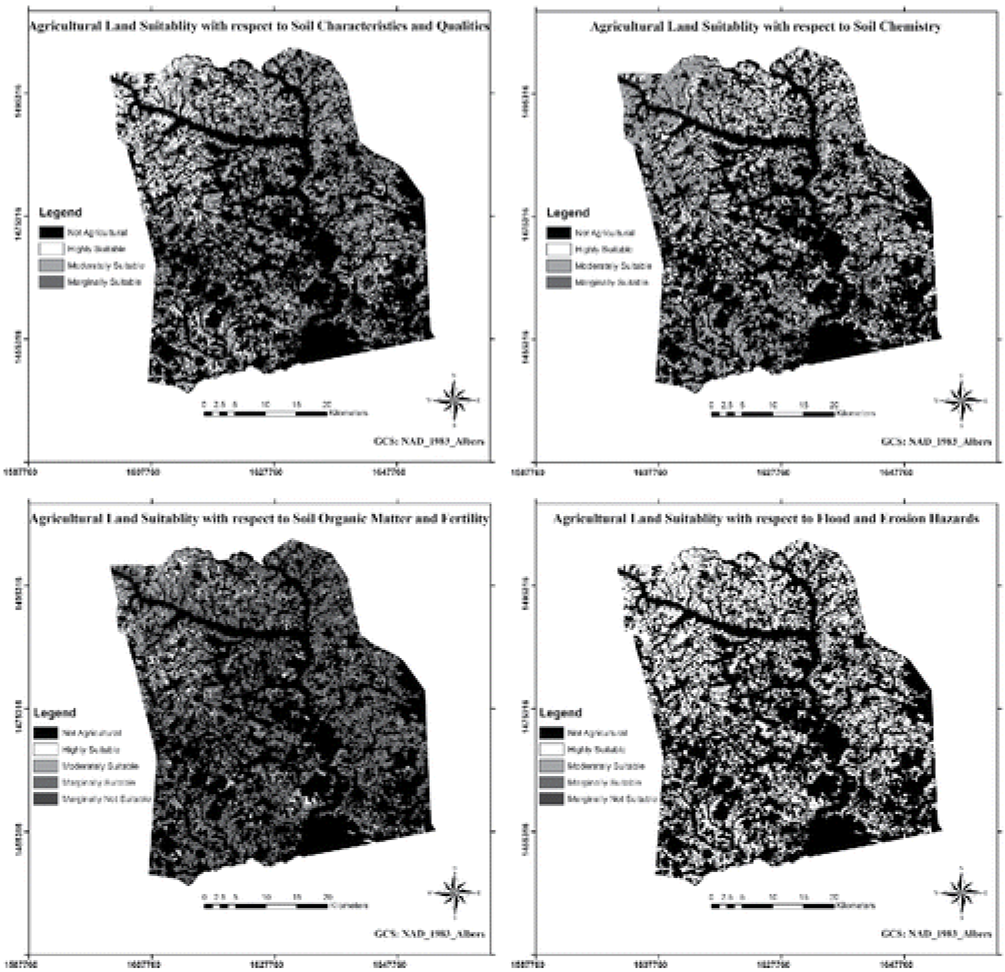

Figure 4. Agricultural land suitability with respect to the major groups of (A) soil characteristics and qualities; (B) soil chemistry; (C) organic matter and fertility; (D) flood and erosion hazards.

After rating land units with respect to the considered criteria, the rating value of each major group of the criteria is calculated by averaging the rating values of the criteria belonging to that group. For example, the rating value of climatic parameters is calculated by averaging the rating values of temperature and total rainfall criteria. Figure 4 shows the suitability results of agricultural lands with respect to four major groups: soil characteristics and qualities, soil chemistry, flood and erosion hazards, and soil organic matter and fertility. Climate parameters does not require mapping because all land units have the same rating value for this major group. Finally, the suitability value of a land unit with respect to all five major groups of the considered criteria is computed by the square root suitability method (Khiddir 1986; Sys, Ranst, and Debaveye 1991):

$$S = R_{min} \times \sqrt{\frac{R_A}{100} \times \frac{R_B}{100} \times \cdots}$$

where S is the suitability value of a land unit, R_{min} is the minimum rating value of the major groups of criteria, and R_A, R_B are the rating values of the major groups of criteria excluding the group with minimum rating value. The process of land suitability evaluation is summarized in Figure 5.

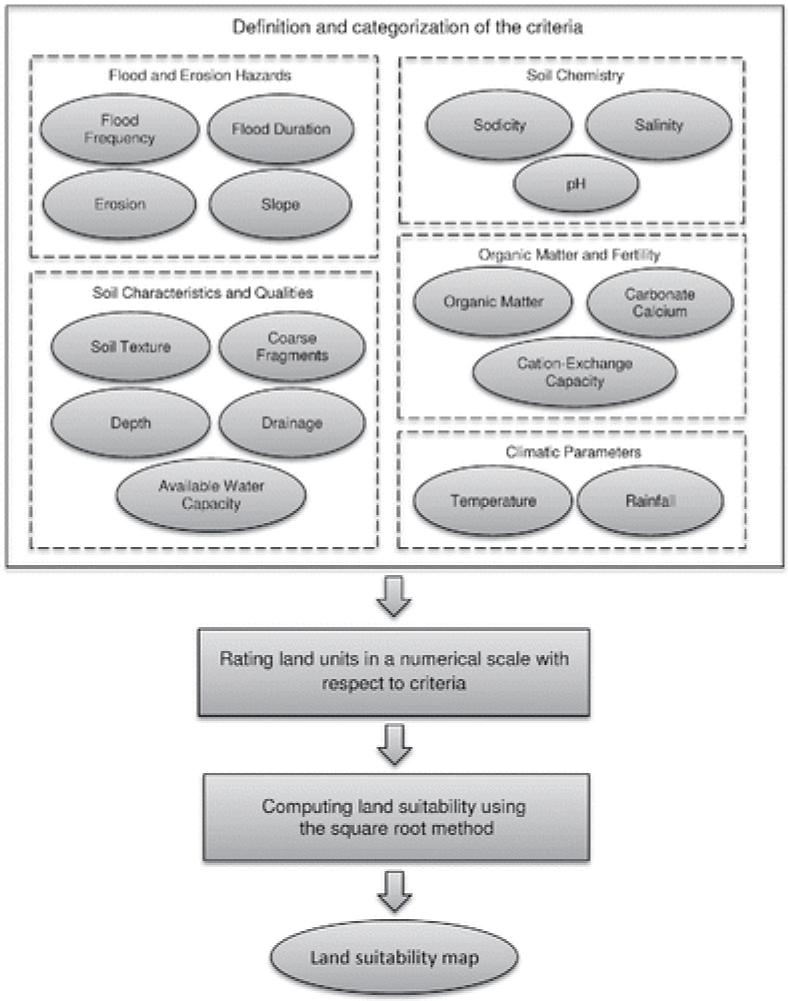

Figure 5. Process of land suitability evaluation.

Results and discussion

Agricultural land suitability evaluation by criteria

Investigation of the influential criteria for the organic production of rain-fed winter wheat shows that climatic criteria including total rainfall and temperature are moderately suitable in Duplin County. In the growing period of winter wheat, the mean temperature of the study area is 12.3°C, which is lower than the optimum range of mean temperature for winter wheat. Also, although the maximum temperature of the study area in this period is less than the allowable upper limit, the minimum temperature is 3°C below the allowable lower limit. Furthermore, the total rainfall is about 550 mm in the growing period of winter wheat in Duplin County, which is adequate for rain-fed wheat cultivation, although not perfect. Therefore, the study area is generally considered moderately suitable with respect to climatic parameters. Table 6 shows the classification of agricultural lands with respect to suitability for each criterion.

Table 6. Classification of agricultural lands with respect to suitability for each criterion.

		Percentage of agricultural lands (%)				
Major group	**Criterion**	**S1**	**S2**	**S3**	**N1**	**N2**
Climatic parameters	Mean temperature	—	100	—	—	—
	Total rainfall	—	100	—	—	—
Soil characteristics and qualities	Soil texture	11	83	3.8	2.1	0.1
	Coarse fragments	100	—	—	—	—
	Available water capacity	9.3	25.6	31. 8	33.3	—
	Depth	100	—	—	—	—
	Drainage	42. 4	34.6	9.3	13.6	0.1
Soil chemistry	pH	17.3	42.2	29.8	10.5	0.2
	Salinity	100	—	—	—	—
	Sodicity (ESP)	100	—	—	—	—
Organic matter and fertility	Organic matter	9.8	75.6	14.6	—	—
	Carbonate calcium ($CaCO_3$)	100	—	—	—	—
	Cation-exchange capacity (CEC)	2.9	1.2	93.5	2.4	2.4
Flood and erosion hazards	Flood frequency and duration (%)	97.3	0.3	1.3	1.1	—
	Erosion (E_w)	12.4	81.7	5.9	—	—
	Slope	96	4	—	—	—

In addition to climatic parameters, two main groups of soil characteristics and qualities and soil chemistry have significant effects on the land suitability for organic production of wheat. Among the criteria considered in the soil characteristics and qualities group, the percentage of coarse fragments and soil depth are highly suitable across the study area. Examination of soil texture shows that 83 percent of agricultural lands are moderately suitable and only 11 percent of them are highly suitable, mostly due to the existence of a high percentage of sand in the soil. AWC is not very suitable in the study area. Only 9.3 percent of farmlands are highly suitable, whereas 25.6 percent and 31.8 percent of them are moderately and marginally suitable, respectively, with regard to AWC. In addition, variation in soil drainage is very high in the study area. Only 42.4 percent of agricultural lands are well drained, and 34.6 percent, 9.3 percent, and 13.6 percent of farmlands are moderately, marginally, and poorly drained, respectively. These results indicate that AWC, soil texture, and drainage are the most important limitations for the organic production of wheat in Duplin County. Figure 4A and Table 6 show the suitability of agricultural lands with respect to the criteria considered in this group. Among the criteria considered in the soil chemistry group, salinity and sodicity are highly suitable in the whole study area, but pH is not as suitable as these criteria. Examination of the soil chemistry shows that soil pH is relatively acidic across the entire study area and therefore agricultural lands are 42.2 percent and 29.8 percent moderately and marginally suitable, respectively, with respect to this criterion (Figure 4B and Table 6).

The fourth group of criteria having potentially meaningful effects on organic wheat agriculture is soil organic matter and fertility. The percentage of organic matter is moderately suitable in agricultural lands of the study area. Results show that 9.8 percent of agricultural lands are highly suitable, and 75.6 percent and 14.6 percent of agricultural lands belong to moderately suitable and marginally suitable classes with respect to this criterion, respectively. In spite of the organic matter, the whole study area is highly suitable regarding the criterion of $CaCO_3$ because its amount is generally very low in the soil. Finally, the amount of CEC is not very suitable in agricultural lands of the study area, such that 2.9 percent, 1.2 percent and 93.5 percent of agricultural lands are highly suitable, moderately suitable, and marginally suitable with regard to this parameter, respectively. As a result, the organic matter and fertility of agricultural lands is one of the main limitations for organic production of wheat in the study area because it cannot be fixed with fertilizers in organic farming (Figure 4C and Table 6).

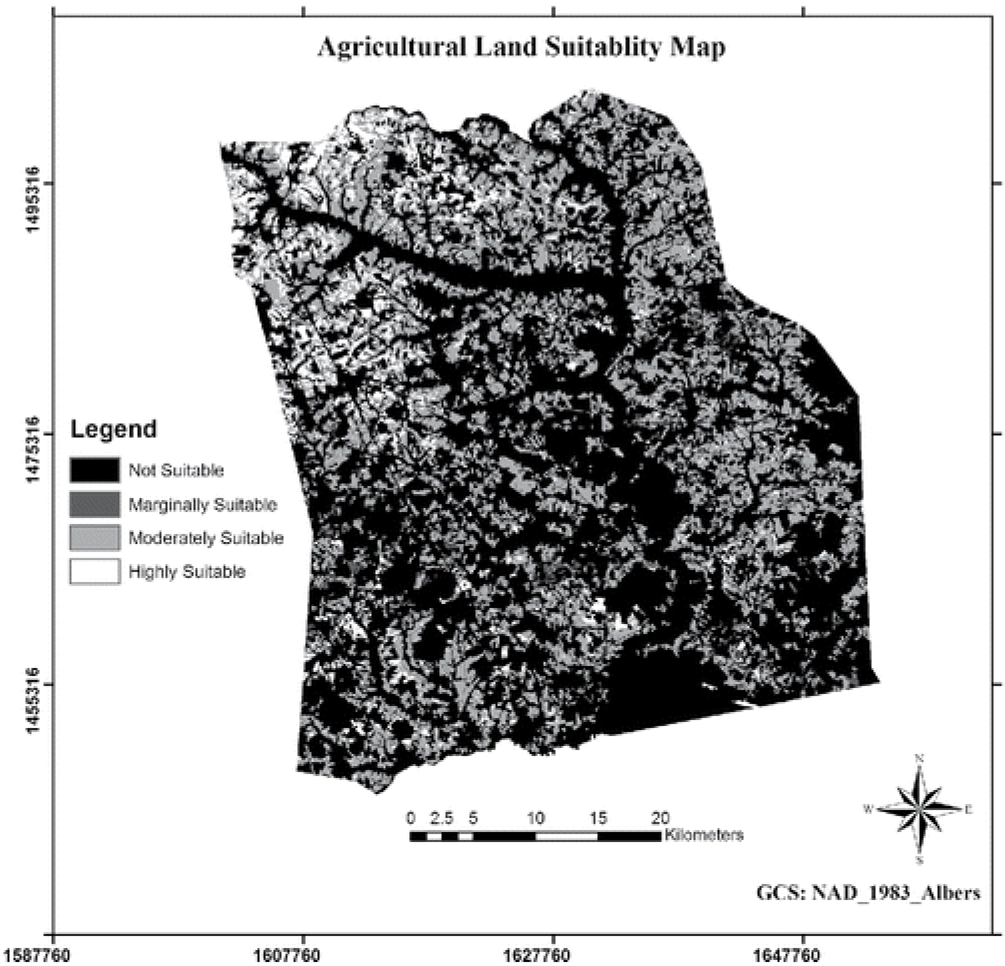

Figure 6. Agricultural land suitability map for organic production of rain-fed winter wheat in Duplin County.

The final group of criteria is flood and erosion hazards. Examination of the criteria of flood frequency and flood duration shows that the study area is mostly safe with respect to flood hazards. Results show that 97.3 percent of agricultural lands are highly suitable with respect to these criteria. In addition, by considering the slope criteria, 96 percent of agricultural lands belong to highly suitable class and the other 4 percent are moderately suitable. The water erosion of soil in the whole study area is somewhat high, however, and therefore little farmland belongs to the highly suitable class with respect to this parameter. Only 12.4 percent of agricultural lands belong to the highly suitable class and 81.7 percent of them belong to the moderately suitable class. Therefore, this criterion is one of the minor limitations of wheat cultivation in Duplin County. Figure 4D and Table 6 display the suitability of farmlands with respect to the criteria considered in this group.

Final agricultural land suitability evaluation

Considering the criteria and suitability method, a composite agricultural land suitability map is generated for organic agriculture of rain-fed winter wheat in Duplin County (Figure 6). The suitability of agricultural lands is categorized into four classes according to the values derived from the suitability evaluations (Table 7). Results indicate that 18.6 percent of agricultural lands in Duplin County are highly suitable for the organic production of rain-fed winter wheat (Table 8). The highly suitable agricultural lands are mostly located in the northwestern portion of the study area where the soil organic matter and fertility as the main criteria for organic wheat production are very suitable (Figure 6). After the northwestern area, the southwestern, northeastern, and southeastern portions of the study area contain highly suitable agricultural lands, respectively. A large proportion (76.8 percent) of agricultural lands of the study area are moderately suitable for this purpose. Due to the lower volume of production and higher economic risk of organic farming compared to conventional farming, however, these areas are not recommended for organic production of winter wheat.

Table 7. Land suitability classes and the corresponding values of suitability index.

Suitability class	Class description	Value of suitability index (S)
S1	Highly suitable	> 75
S2	Moderately suitable	50–75
S3	Marginally suitable	25–50
N	Not suitable	< 25

Table 8. Agricultural land suitability results for organic production of rain-fed winter wheat in Duplin County.

Suitability class	Area (ha)	Area (%)
S1	14072.2	18.6
S2	58086.1	76.8
S3	3270.3	4.3
N	220.3	0.3

Conclusion

Despite having less detrimental effects on the environment and human health, organic farming practices are infrequently implemented in the United States because of their lower productivity relative to those of conventional agriculture. One of the best solutions to overcome this problem is land suitability evaluation for finding the fertile lands that naturally need fewer chemical fertilizers for cultivation. Using land suitability evaluation for organic farms can significantly reduce the economic risk of organic food production. There is much literature on agricultural land suitability, but relatively few papers emphasizing organic production. To address that gap in the literature, a novel land suitability evaluation for organic farming has been presented that combines GIS, multicriteria analysis, and the square root method, using Duplin County, North

Carolina, where the economy heavily depends on agriculture, as a case study. This method can be easily used in other counties of the coastal plain with modified criteria. In addition, the proposed method can be generalized to the organic cultivation of other crops by considering their specific requirements.

The influential criteria of organic matter and soil fertility are considered as a distinct major group in this study. Low organic matter and fertility generally result in lands being unsuitable for organic agriculture of winter wheat. In conventional farming, low values of these characteristics are not considered major limitations because they can be compensated for using fertilizers. Our analysis demonstrates that 18.6 percent of agricultural lands in Duplin County are highly suitable for organic rain-fed winter wheat. Additionally, 76.8 percent of the agricultural lands in Duplin County are moderately suitable for organic rain-fed winter wheat. Thus, 95.4 percent of land is moderately or highly suitable, indicating that the study area has significant potential for organic agriculture of winter wheat. The major physical limitations of organic wheat agriculture on established farmlands in the study area are related to soil available water capacity, erosion hazards, and organic content and fertility, with soil texture, drainage, and soil pH also marginally affecting the land suitability in some areas.

Although a relatively complete collection of criteria is considered to assess agricultural land suitability in this study, all of the considered criteria are related to the physical environment. Socioeconomic criteria such as accessibility to transportation networks, transit costs and availability, and cost of the labor force can be considered in future research to improve the results of suitability evaluation. Considering these criteria can make economic evaluation possible and reduce the risk of organic agricultural production by maximizing the production profit. Furthermore, a new grouping of the considered criteria is conducted in this study for estimating the final suitability index. Related criteria with the same importance are grouped together and finally, the organized groups contribute with equal weights in the suitability evaluation. The important criteria can be considered individually or as members of groups to adjust their weightings in the final suitability index. Although grouping partly manages different importance values of the criteria, multicriteria decision-making methods such as AHP, Analytic Network Process (ANP), FAHP, and Fuzzy Analytic Network Process (FANP) can be used to estimate different weights for the considered criteria in future research. Projection pursuit classification might also be used to categorize the criteria.

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